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A SOLAR ENERGETIC PARTICLE EVENT WITH $^{3}He/^{4}He > 1$

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A SOLAR ENERGETIC PARTICLE EVENT WITH $^3He/^4He > 1$

The observation of γ-rays and the short-lived isotope ^3H provides evidence for the occurrence of nuclear reactions by high-energy particles accelerated in solar flares.[5,1] At the same time stable isotopes such as ^2H and ^3He should also be produced in these same reactions. The presence of ^3He in solar energetic particles was first detected by Hsieh and Simpson.[12] In the energy range 10-100 MeV/nucleon, they obtained $^3He/^4He = (2.1 \pm 0.4) \times 10^{-2}$ by summing over 7 solar particle events. In later work, Garrad et al. (1973)[8] and Anglin et al. (1973b)[2] have reported that $^3He/^4He$ was highly variable from event to event. For example, Garrad et al. have reported an event on 14th October 1969 in which $^3He/^4He = 0.26 \pm 0.08$ and Anglin et al. (1974)[3] have detected an event on 30 July 1970 where $^3He/^4He = 0.54 \pm 0.09$. In these "$^3He$ rich events", ^2H and ^3H were not detected and the resulting upper limits were much less than expected from the theory of nuclear reactions.[14] These events were small, and the number of ^3He observed was low (~70). This anomolous production of ^3He should provide new insight into the acceleration and confinement process of energetic particles in solar flares.

Using the Goddard Cosmic Ray telescopes on OGO-V[17] we have detected an unusual solar event on 28 May 1969. The flare associated with the event occurred at 12:48 on 28 May and had importance 1B. The solar coordinates of the event are 10°N and 56°W with the associated McMath plage region 10109. About 600 ^3He nuclei were detected in this event and the $^3He/^4He = 1.52 \pm 0.1$ in the energy range 4-80 MeV/nucleon. This is the highest ratio reported so far for any solar event.

In Fig (1) the mass histograms for He nuclei are given. The good resolution of ^{3}He and its dominance in this event are clearly seen. The dotted curve represents the mass distribution (normalized at the peak of ^{4}He distribution) for another event on 2 November 1969. For this latter event we get $^3He/^4He = 0.08$ in excellent agreement with Dietrich.[6]

The hydrogen to helium ratio for the event on 28 May is also highly unusual with $^1H/(^3He+^4He) = 1.00 \pm 0.05$. when compared to the values of 60-100 obtained by Lanzerotti and Maclennan[13] and ~100 by Hseih and Simpson[12] by averaging over a number of events.

The energy spectra of three components were all consistent with power laws in kinetic energy/nucleon. The exponents for ^{1}H, ^{3}He and ^{4}He were -4.29 ± 0.10, -4.16 ± 0.10 and -4.04 ± 0.11, respectively.

The observed upper limit to $^3He/^4He$ in the solar chromosphere was $(1 \pm 0.5) \times 10^{-3}$ (Namba[15]). In the solar wind $^3He/^4He \sim 10^{-4}$ (Bame et al.[4]; Geiss et al.[9]). The solar particles have higher relative abundance of ^{3}He in comparison with the solar chromosphere. The $^4He/^1H$ is also large compared to the observations on solar prominences[10]. In table (1), the isotopic abundances of He as obtained from several related studies are shown for comparison.

Ramaty and Kozlovsky [16] have proposed a theory dealing with the production of ^{2}H, ^{3}H and ^{3}He in solar events. They have taken into account effects of kinematics of the reactions and the possible anisotropy of solar beams to explain the anomolously small ^{2}H and ^{3}H abundances compared to ^3He. They find that for energetic protons and ^4He nuclei incident on the solar atmosphere, ^3He will be preferrentially emitted in the direction opposite to that of the incident particle while ^2H and ^3H will tend to have the same direction. For the giant flare in August, 1972 (Webber et al.)[18], they arrive at about 2 gm/cm^2 to account for $^3He/^4He$ of $\sim$.02 observed in the event. They also relate the γ-ray intensities observed by Chupp et al.[5] with the energetic protons observed in the event. The large ratio of $^3He/^4He$, according to Ramaty and Kozlovsky, occurs only at low energies (about 0.1 MeV/nucleon) and so the authors point out that some post acceleration is necessary to account for the observed particles.

Using the same model to explain the very high $^3He/^4He$ ratio in the 28 May event requires the passage through 2.3 nuclear mean free paths or some 170 g/cm^2 of material for protons. This further requires that the ionization energy loss be balanced by continuous acceleration which means that 50 MeV/nucleon He nuclei would have to receive a total energy of $\sim$12 GeV. This appears highly implausible. One possible clue may be provided by the simultaneous observation of the solar x-rays and electrons. Here it is found that only 10^{-2} - 10^{-3} of the electrons escape with a large fraction incident on the lower corona which produces the x-ray emission. A similiar effect may be occurring with the nuclear component though the rigidities of the nuclear particles are larger by factors $>10^2$. The other secondary products ^2H and ^3H are not seen in this event. Assuming that one nucleus of ^2H(or ^3H) was seen during the event, the upper limit for $^2H/^3He$ (or $^3H/^3He$) is $\sim$ 1/600. Simultaneous γ-ray observations would be of great value in identifying the type of process and the time scale on which it operates. These were not available for this event. It is also possible that the solar material involved in these flares has an anomalous composition to start with.

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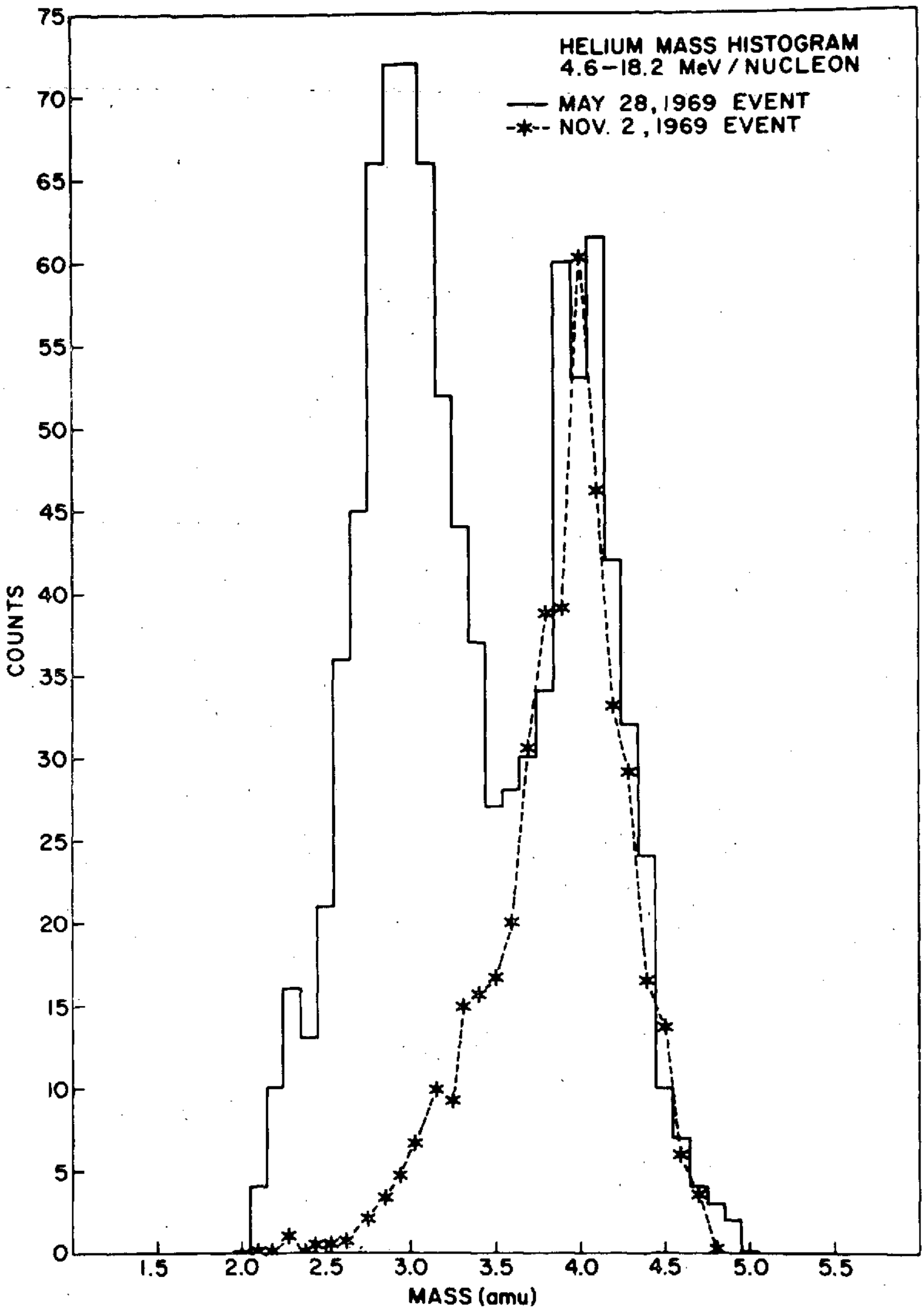
Table 1 Relative abundance of He isotopes

$^3He/^4He$	$^4He/^1H$	$^3He/^1H$
SOLAR PARTICLE EVENTS:	SOLAR PARTICLE EVENTS:	SOLAR PARTICLE EVENTS
1.52 ± 0.1 28 May 1969 (This paper)	$0.40 \pm .04$ 28 May 1969	0.60 ± 0.05 28 May 1969
0.54 ± 0.09 30 July 1970 Anglin et al.[3]	$\sim 10^{-2}$ Average of 7 flares in 1967 (Hseih & Simpson)[12]	~ 0.09 30 July 1970
0.26 ± 0.08 14 October 1969 Garrad et al.[8]	$\sim 1.7 \times 10^{-2}$ Lanzerotti and Maclennan[13] (Average of 7 large flares in solar cycle 20)	~ 0.005 14 October 1969
0.077 ± 0.02 2 November 1969 Dietrich[6]	$\sim 1.4 \times 10^{-4}$ 25 September 1969, Dietrich & Simpson[7]	~ 0.0005 general range of occurrence in ordinary solar events
0.021 ± 0.004 Average of 7 flares in 1967 (Hseih & Simpson[12])		
CHROMOSPHERE:	CHROMOSPHERE & PROMINENCES	
$\leq (1.0 \pm 0.5) \times 10^{-2}$ Namba[15]	~ 0.06 Hirayama[10]	
SOLAR WIND	SOLAR WIND	
4×10^{-4} Geiss et al.[9]	~ 0.045 Hirshberg[11]	
$\leq 4 \times 10^{-4}$ Bame et al.[4]		

Figure Captions

Fig (1) Mass histogram for He nuclei observed in the solar particle events on 28 May 1969 and 2 November 1969. Note dominance of ^{3}He in the 28th May event. The $^{3}He/^{4}He$ ratio for the 2 November event is 0.08 in agreement with that reported by Dietrich.[6]


HELIUM MASS HISTOGRAM
4.6–18.2 MeV / NUCLEON
MAY 28, 1969 EVENT
NOV. 2, 1969 EVENT
COUNTS
MASS (amu)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5

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